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Kawasaki's steam injected gas turbine base rated at 2370 kW & 33% efficiency

By Robert Farmer

Company's M1A-13CC engine, nominally rated at 1240 kW electrical and 20% simple cycle efficiency with losses, can be steam injected to 2370 kW and 33% efficiency — is being packaged in standardized cogen plant design priced at an estimated $2-$2.2 million installed.

In April, 1988, Kawasaki Heavy Industries (KHI) began operation of a steam-injected Cheng cycle gas turbine demonstration plant at its Akashi Works in Japan. The plant is tied into the factory complex through steam and electric power interties to supply variable amounts of steam and electricity according to daily and seasonal factory demands.

In base load operation, the powerplant is designed to provide some 2.4 MW electrical output and, simultaneously, a maximum steam output of over 13,000 pounds per hour — at an overall efficiency of nearly 60 percent.

In addition to serving as a steam and power generator, the Akashi installation provides a functional testbed for company gas turbine product developments and modifications as well as new component and new product testing of gas turbines and auxiliary systems.

The demonstration set is built around a dual-fuel M1A-13 gas turbine modified for steam injection; supplementary-fired heat recovery boiler; epicyclic reduction gearbox; 60Hz electric alternator; and computerized plant control and monitoring equipment.

The M1A-13 gas turbine is itself a new model based on an uprated and improved version of KHI's existing M1A-01/03 series. In addition to the steam-injected model, a non-steam injected version is being introduced — as is a lower-output derated model and a "twin-pack" design with integral combining gearbox.

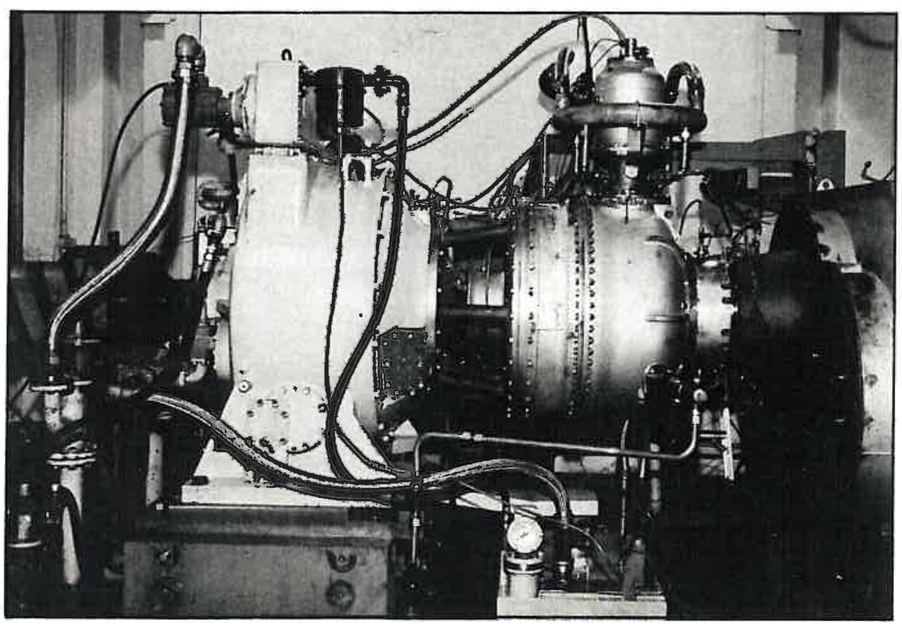
All these machines are slated for market introduction and delivery this year. Here's the lineup:

☐ **M1A-11.** ISO base rated 1,250 kW at the output shaft, natural gas fuel, with approximate 25% simple cycle efficiency. Basically a derated -13 with lower 900°C firing temperature. Available initially as non-steam injected machine for conventional cogeneration and base load genset applications. First deliveries slated this December.

☐ **M1A-13.** Rated 1,570 shaft kW with nominal 26% efficiency at ISO base conditions on gas fuel. Firing temperature of 1030°C base load produces power and efficiency gains over the -11. Production machines set for July 1989 delivery for conventional cogen, CHP or simple cycle power generation projects.

☐ **M1T-13.** Twin-turbine design with -13 machines driving parallel-shaft combining reduction gearbox. Nearly twice the output of two -13's at 3,052 skW, with only slightly reduced efficiency of 25.2% ISO base load simple cycle. Weighs 6100 kg, measures only 2.3 x 2.2 x 1.6 meters complete with two turbines, gearbox and skid. Set for commercial deliveries starting this July.

☐ **M1A-13CC.** Cheng cycle steam injected design is a modified -13 with design and component changes to handle increased flow and output with steam injection. ISO base rated 2,570 skW and 35% efficiency with full 10,400 lbs/hr steam injection. Complete packaged sets with boiler, controls and auxiliaries ready for turnkey installation starting this December.



M1A turbine, modified for Cheng cycle steam injected operation, on factory test in early 1988. Engine packaged with pedestal-mounted reduction gearbox weighs 3300 kg, measures 2.3 x 1.5 x 1.8 meters.

All of these new models trace their roots to KHI's M1A-01 and -03 machines that were introduced in the late 1970's and early '80's. Accordingly, the M1A series itself is based on a scaled-up version of Kawasaki's first gas turbine design, the 220-kW S1A machine. This series began development in 1973 with first commercial applications in 1977, and is still in production.

Common design features throughout the family include single-shaft twin bearing design with centrifugal compressor and axial turbomachinery; single can-type tangentially-mounted combustor; output drive at the "cold" compressor end; axial straight-through exhaust; and integral reduction gearbox to step 22,000 rpm turbine speed down to 1500 or 1800 rpm.

The physically larger M1A series all feature two stages of centrifugal compressor impellers coupled with three axial turbine stages. Earlier model -01 machines, incidentally still in full production, utilize an uncooled turbine at a modest 900°C base load turbine inlet temperature on natural gas fuel. TIT is upped to only 920°C in peaking rating on distillate oil.

Market introduction of the higher-output -03 version in 1982 saw application of air-cooled blades and vanes to the first state turbine to accommodate the 960°C base load (gas fuel) and 975°C peak load (distillate) firing temperature.

In a sense, these -01 and -03 models are purpose-built for two different applications, with design and materials spec'd to each role. Peaking units, intended for quick loading in emergency/standby service, use roller and ball bearings for rotor support and thrust; a primary liquid fuel combustion system with gas or dual fuel optional; and thermal shock-resistant materials and coatings on turbine airfoils.

Base load units, on the other hand, feature white metal sleeve bearings at the compressor end, although retaining the antifriction rear bearing; a primary natural gas fuel system; and revised turbine airfoil materials and coatings for continuous duty and erosion/corrosion protection.

The new -11 and -13 turbines are specifically designed for full-time base load operation, on natural gas fuel primarily, although distillate and dual-fuel systems are available. Shaft support and thrust is via sleeve bearings all around — white metal at the compressor end and aluminum alloy at the turbine shaft end.

The turbine section features a fully air-cooled first stage with CoCrAlY coating on the rotating blades to provide sodium and sulfur corrosion protection. Turbine blades at stage one and two are cast Inco 792K, vanes of X-45. Third stage blades are Inco 713C castings with vanes of heat-resistant steel.

The ISO base load turbine inlet temperature, burning gaseous fuel is 1030°C for the -13 unit, derated to 900°C for the lower output -11 model. With a higher firing temperature regime, exhaust gas temperature is also increased somewhat, although the cycle efficiency is also improved.

For example, the -13 model shows a higher exhaust gas temperature at 555°C ISO base load than the original -01 version that produced exhaust at 515°C base. And the -13 simple cycle efficiency is 26% as opposed to the -01 rating of less than 21%. Makes the new model a much more attractive match for heat recovery applications, note KHI engineers.

Interestingly, the new models feature an approximate 20% reduction in mass flow compared to earlier designs. For example, at ISO base conditions, the M1A-13 has a mass flow rate of 7.3 kg/sec compared to the M1A-03 model's 9.1 kg/sec. According to company design engineers, this reduction follows as a function of improved aerodynamics in the compressor and turbine flowpath. Other specific design changes over the earlier models include:

☐ *Compressor.* Improved efficiency with new high backward-angle geometry impeller designs. High area ratio diffuser design and new return channel. Impeller fabricated in titanium rather than stainless steel for lighter weight, reduced rotational mass.

☐ *Turbine.* Improved aerodynamics with airfoil design for controlled vortex flow pattern and optimum work per stage. Installation of abradable seals and rubbing tips for reduced leakage. Reduced cooling air required with new-design impingement cooled vane and pinfin cooled blade at the first stage.

☐ *Combustor.* Laminated porous wall construction in Haynes 188 alloy, coupled with new ceramic thermal barrier coating provides long life at higher combustion temperatures. Reduced

Steam-Injected M1A-13 Engine Performance

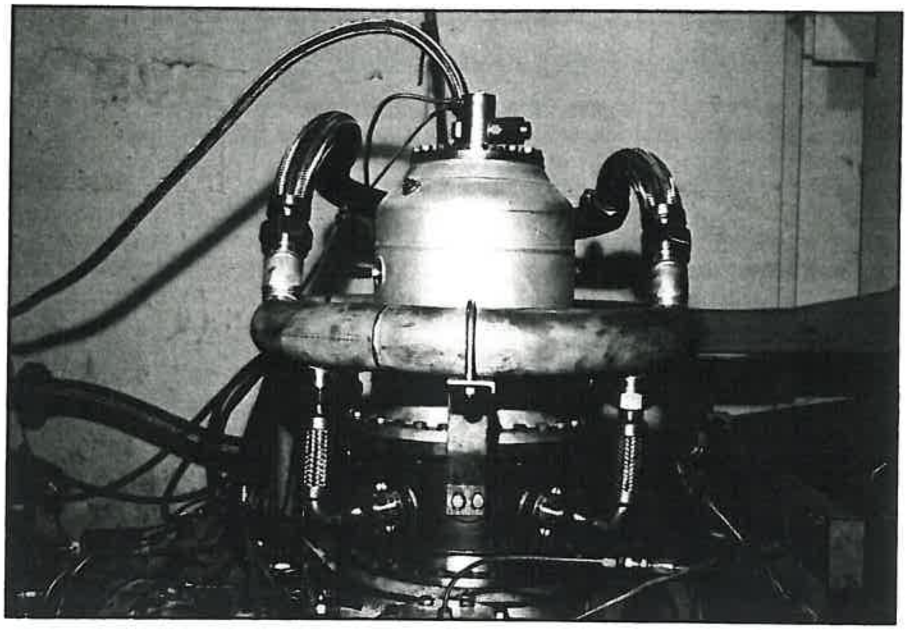
Modified M1A-13CC engine with Cheng Cycle steam injection shows slightly derated output with no steam injected as compared to the conventional -13 design. Full steam injection rate is approximately 10,400 lbs per hour. Performance figures at ISO base load output, natural gas fuel, no losses.

Parameter	No Steam Injection	Full Steam Injection
Shaft output	1,375 kW	2,570 kW
Heat rate (per kWh)	15,150 Btu	9,750 Btu
Efficiency	22.5%	35.0%
Air flow (per sec)	16.0 lb	15.6 lb
Pressure ratio	7.8:1	9.2:1
Turbine inlet temperature	1850°F	1850°F
Exhaust gas temperature	1070°F	1065°F

M1A-13CC Cheng Cycle Cogen Performance

Estimated plant performance with gas turbine operating at constant base load firing temperature at ISO conditions, with 4" H_2O inlet, 16" H_2O exhaust duct losses, on natural gas fuel. Saturated steam at 220 psia with 59°F boiler feedwater temperature.

	Boiler in Unfired Condition		Boiler Supplementary Fired	
Parameter	W/O Injection	W. Full Injection	W. Full Injection	W/O Injection
Electrical Output	1,240 kW	2,370 kW	2,370 kW	1,240 kW
Process Steam (per hour)	10,360 lb	0	13,200 lb	18,920 lb
Injection Steam	0	10,400 lb	10,400 lb	0
Turbine Fuel (per hour)	21.10 mmBtu	24.75 mmBtu	24.75 mmBtu	21.10 mmBtu
Boiler Fuel (per hour)	0	0	15.80 mmBtu	10.25 mmBtu
Electrical Efficiency	20.1%	32.7%	n/a	n/a
Overall Efficiency	77.6%	32.7%	58.1%	84.2%



Close-up view of steam injection manifold and distribution ports on modified combustor. This is a pre-production prototype at the Akashi Works test cell. Full steam flow at 100% injection rate is 10,400 lbs/hr.

mass flow means less pressure loss through the reverse-flow combustor and outlet scroll.

☐ *Casings.* Revised casing flange seal designs to reduce air leakage. Overall mass flow reduction lowers exhaust pressure losses to increase operating efficiency.

Cogeneration Applications

To date, the majority of the nearly 300 M1A gas turbines in operation or on order are applied for emergency/standby generation duties. The primary market has been in Japan where M1A's serve as backup units in hospitals, apartments, office buildings. schools and other public buildings.

Government regulations require all public buildings over a certain size be provided with 100% emergency power generation capacity in case of a break in the mains. This legislation, passed in the late 1970's, created an immediate market for domestically-produced gas turbine generator sets for standby service, the M1A included.

However, with the considerable efficiency improvements and output increases in the latest M1A models, it is apparent that KHI intends these new machines for continuous base load operation primarily in cogeneration and CHP applications — not only in Japan but in all industrialized nations.

Company marketing managers point out that, as of mid-1988, some 40 KHI gas turbines were installed for cogeneration service — with seven of these in operation or under construction at projects in the U.S.A.

According to GTW estimates, roughly 70% of these cogen plants — some 30 gas turbines — are the M1A designs, the remainder being the smaller S1A and S2A units.

High time cogen unit in the U.S. is an M1A-03 set installed in 1984 for process steam and power production at a Dial Chemical facility in Los Angeles, Calif. It has over 23,000 hours operation at rated 1,350 kWe output with water injection for NOx reduction to meet strict State regulations.

According to Dr. Yukio Otsuki, General Manager of Kawasaki's Industrial Gas Turbine Group, a conventional non-steam injected M1A-13 plant is best suited to cogeneration systems where there is little variation in steam or electric power requirements throughout the year — or for sites where there is no need (nor incentive) to increase electric power production during certain periods.

The conventional cogen set is also seen as the best match for certain industrial applications where hot gas rather than steam is the main process requirement — services such as products drying, food processing and some chemicals production.

A conventional cogeneration package built around the M1A-13 gas turbine will provide some 1,500 kW of electric power at ISO base load conditions, burning natural gas fuel. Overall system generating efficiency is 25% with no heat recovery factored in. "However," notes Dr. Otsuki, "with full steam recovery from an unfired boiler

Uprated M1A-Series Performance

New models' nominal performance figures at ISO base load conditions, without duct losses, burning natural gas fuel. M1T version is a twin gas turbine design driving into combining gearbox. The "CC" model is Cheng Cycle steam injection, with all figures here for maximum steam injection into the gas turbine with unfired boiler conditions.

	M1A-11	M1A-13	M1T-13	M1A-13CC
ISO Base Output (Shaft, Natural Gas)	1,250 skW	1,570 skW	3,052 skW	2,570 skW
Heat Rate ISO Base (Natural Gas)	13,840 Btu/kwh (14.6 MJ/kwh)	13,150 Btu/kwh (13.9 MJ/kwh)	13,520 Btu/kwh (14.3 MJ/kwh)	9,750 Btu/kwh (10.3 MJ/kwh)
Efficiency	24.7%	26.0%	25.2%	35.0%
Turbine Inlet Temp (Base Load)	1650°F (900°C)	1885°F (1,030°C)	1885°F (1,030°C)	1850°F (1,010°C)
Mass Flow	16.3 lb/sec (7.4 kg/sec)	16.1 lb/sec (7.3 kg/sec)	32.2 lb/sec (14.6 kg/sec)	15.6 lb/sec (7.1 kg/sec)
Pressure Ratio	9.0	9.0	9.0	9.2
Exhaust Temp	878°F (470°C)	1030°F (555°C)	1030°F (555°C)	1065°F (575°C)

at base load electric output, efficiency rises to nearly 80%." It is even higher than that in applications where the exhaust gas is utilized directly, he maintains.

Turnkey price for an M1A-13 cogeneration package is said to be between $1.6 and $1.8 million — including the gas turbine and reduction gear, controls and auxiliaries, driven electric alternator, inlet and exhaust duct treatment and filters, and heat recovery boiler.

That is for skid-mounted package, with enclosure, installed on a customer-supplied foundation. At its 1460 kW simple cycle electrical base load output, including all losses, this works out to around $1100 to $1235 per kW installed.

Cheng Cycle Cogeneration

In 1987, Kawasaki signed agreements with International Power Technology, Redwood City, Calif., to become the exclusive worldwide licensee for IPT's patented Cheng cycle products based on gas turbines rated between 500 kW and 2,000 kW unit output.

The Cheng cycle is essentially a steam-injected gas turbine technology that integrates a heat recovery boiler with a steam injected gas turbine design and a sophisticated turbine/boiler control system to optimize plant output and efficiency.

"Basically, the cycle provides the cogeneration operator with an extremely wide range of electrical and steam outputs designed to match daily and seasonal fluctuations in both electric power and process steam demand," explains Rick Held, Director of Business Development at IPT. "With the gas turbine at constant firing temperature, it's possible to nearly double turbine electric power output by injecting steam. This might be used to take advantage of particularly valuable periods of electricity production when process steam loads are low."

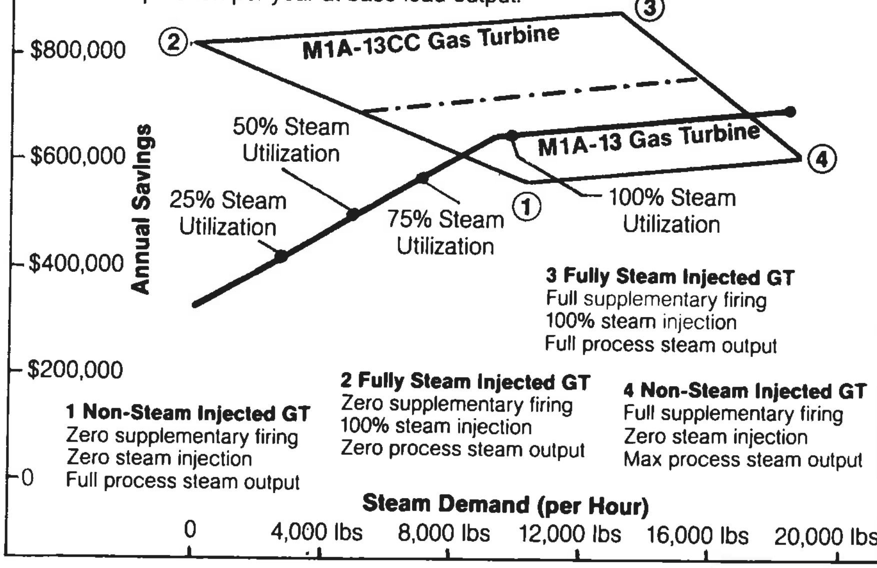
At times when both process steam and electric power demands are high, the boiler is supplementary-fired to match the higher process demands — and provide full steam injection for maximum power output. All this is done with the gas turbine at base load constant firing temperature.

For further refinement in matching process and power requirements it is possible to vary 1) the gas turbine inlet temperature, 2) amount of steam injected into the turbine, and 3) the amount of supplementary firing in the boiler.

This offers users an extremely flexible performance envelope to exactly match varying site demands — at maximum operating efficiency and maxi-

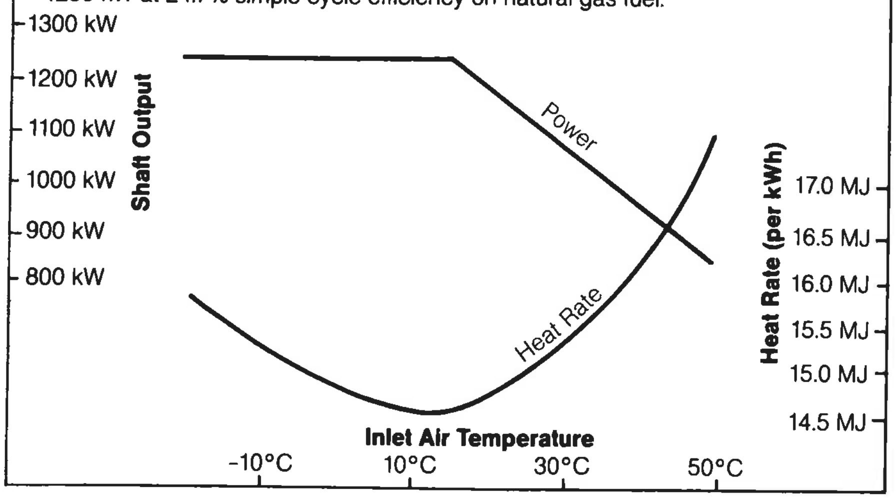
Payback on M1A-13 and -13CC Cogen Installations

Annual cogeneration savings projected for the M1A-13 (non-steam injected) and M1A-13CC (steam injected) gas turbine plants versus process steam demand. Evaluated on the basis of 8¢ per kW cost of electricity, 8¢ per therm for fuel, and 8200 hours of operation per year at base load output.



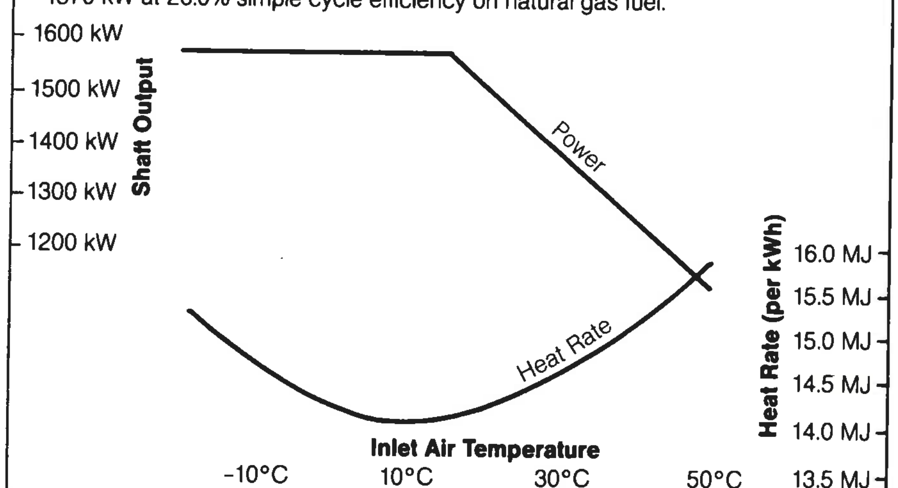
M1A-11 Design Performance

At 15°C sea level, without duct losses, the M1A-11 has a shaft output rating of 1250 kW at 24.7% simple cycle efficiency on natural gas fuel.



M1A-13 Design Performance

At 15°C sea level, without duct losses, the M1A-13 has a shaft output rating of 1570 kW at 26.0% simple cycle efficiency on natural gas fuel.



mum profitability for each level. An added bonus with steam injection is that NOx control is "built in."

In order to handle the increased output with steam injection, the M1A-13 design is modified substantially to become the M1A-13CC designation. The combustion system casing and liner are beefed up with heavier-duty components, fitted with steam injection supply pipes, ring manifold and injection ports.

Overall compressor pressure ratio is reduced from 9.0 to 7.8 to 1 in the non-injected mode of operation. The first and second stage turbine nozzles have a greater throat area to handle the increased mass flow. In addition, the torque transfer shaft has a stronger design spline area (to allow for the higher power output) and the reduction gearbox is redesigned from 2,200 hp to 4,000 hp capacity.

According to KHI and IPT market research, Cheng cycle cogen performance proves most valuable for the small operation — in the 1,000 kWe to 4,000 kWe range. "Hospitals, universities, large hotels and large mixed-use complexes characteristically have steam and electricity requirements that change significantly both daily and seasonally," explains Held. "In addition, many small to medium-size industrial plants have intermittent processes which can also force large swings in the process steam requirements."

The wide operating flexibility of the Cheng cycle also fits the standard plant design to more application requirements than a conventional cogeneration system. Packages are customized to the extent that there is a selection of generating voltages and type of fuel system — but, beyond these, all plants are essentially the same.

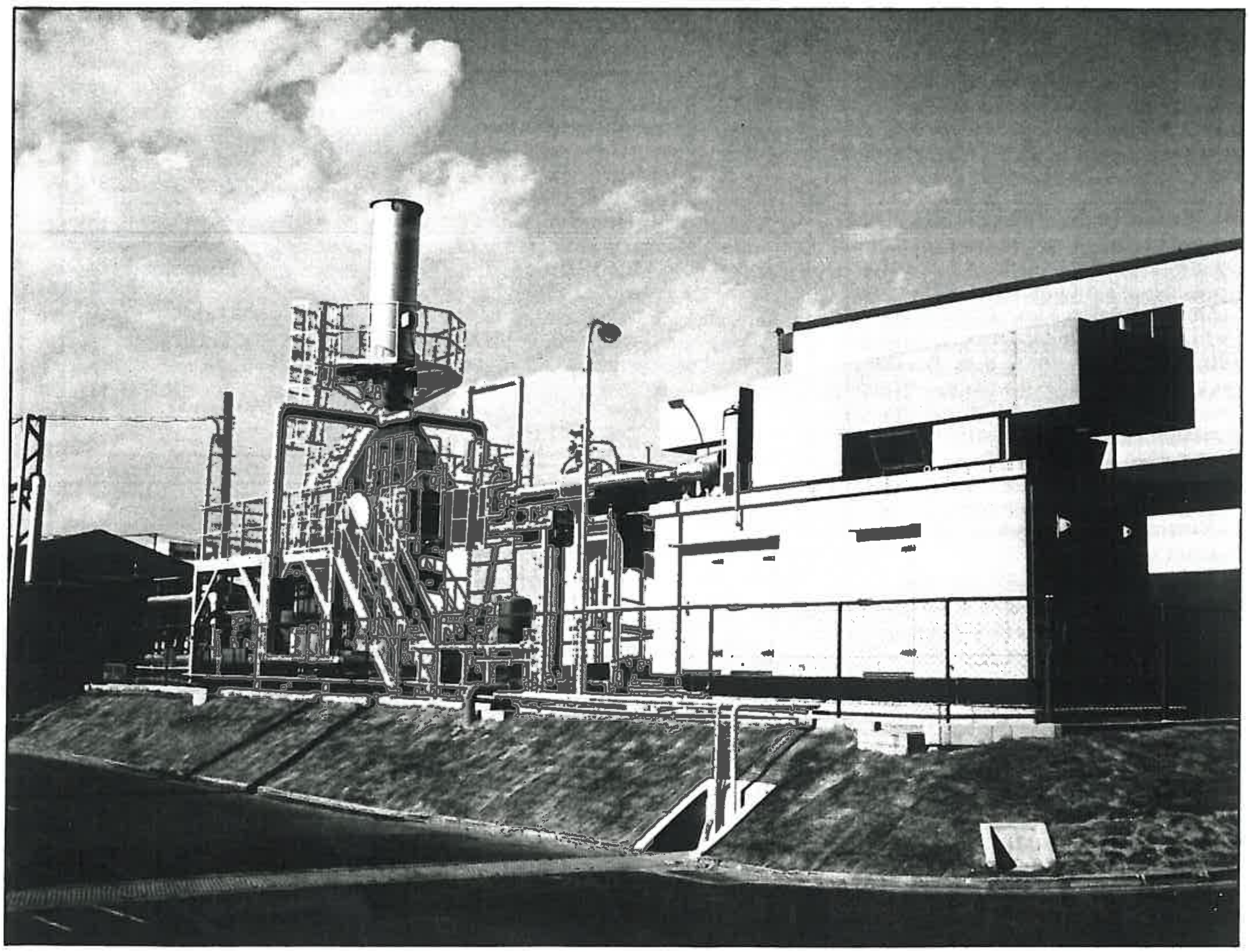
"A standardized plant design provides the customer with at least two advantages," explains Dr. Otsuki. "First, installed cost is reduced due to much lower site-specific design, engineering and installation costs.

"Second, system reliability is improved due to pre-assembled and factory-tested equipment. This eliminates some of the costly surprises customers can experience due to installation mistakes or design changes."

KHI is pegging the turnkey price of a M1A-13CC package at between $2.0 and $2.2 million. At its 2370 kW/electrical base load plant output rating, with losses and full steam injection, the installed cost works out to around $840 to $930 per kW installed.

Depending upon retail electric prices, utility buyback rates, cost of fuel and process and electricity requirements, KHI expects that most U.S. cogeneration customers can look to a turnkey plant payback of 2 to 3 years based on 8200 hours per year operation.

For North American cogeneration applications, and the full line of Kawasaki gas turbines, KHI has contracted with U.S. Turbine in Maineville, Ohio and Cullen Detroit Diesel in Surrey, B.C. Canada to provide packaging, sales, installation and after-sales service.



KHI's demonstration plant at Akashi Works in Japan. Cheng cycle M1A package supplies the factory with varying amounts of steam and electric power — controlled entirely by automatic computerized system to produce maximum efficiency at each power/steam flow setting.

ENGINEERING NEWS AND TRENDS

Nearly 275 M1A units are in commercial service

KHI engineers used the existing M1A-03 series as the reference base for the new uprated design series. Higher output and efficiency achieved through component design inprovements and increase in turbine inlet temperature.

M1A design was launched in 1978 as the -01 model at an 1170 kW base load rating on natural gas fuel. First uprated in 1982 to 1465 kW shaft output base load to become -03 model featuring air-cooling and 60°C increase in firing temperature.

Both the -01 and -03 models are still in production. As of mid 1988, nearly 300 M1A series units had been installed or on order — about 275 of them in service. Most have been installed in Japan as emergency standby gensets for schools, hospitals and other public buildings.

KHI with new M1A engine designs in 1.5 to 3 MW

Kawasaki Heavy Industries is bringing out a new uprated line of its existing M1A model series — with higher unit outputs and better efficiencies.

New designs are available in conventional as well as steam injected (Cheng Cycle) versions. All models will be ready for delivery this year starting with single and twin M1A-13 units in July.

Ratings range from 1250 skW (gas turbine output shaft power) to 2570 skW with steam injection.

Basically all M1A's have similar design features

All the Kawasaki M1A engine frames are basically the same. Feature a two-stage centrifugal compressor and three-stage axial turbine on a single shaft; single large tangentially mounted combustor with a single fuel nozzle; axial straight-through exhaust; epicyclic reduction gearbox to step down 22,000 rpm shaft speed to 3000/3600 rpm for 50/60 Hz generator drives.

Differences in output ratings are basically a function of turbine inlet temperature; compressor air flow and pressure ratio; cooling air flow; turbine airfoil design and cooling techniques.

Improved -13 model more efficient & more powerful

Latest M1A-13 design, for example, has 7% more power output than its M1A-03 predecessor and 16.3% lower heat rate. KHI engineers point out this was done with a 125°F increase in turbine inlet temperature — but with a 20% reduction in air flow.

Basically attributed to improved efficiency in both the compressor and turbine sections (through better aerodynamics); reduction in turbine blade leakage; reduced turbine cooling requirements and lower combustor pressure losses; higher combustor temperature with improved wall structure design and coatings; lower exhaust back-pressure losses and lower overall air leakage.

FERC approves N.E. gas pipeline for Canadian imports

U.S. Administrative Law Judge has granted Federal Energy Regulatory Commission permission to issue construction permits to three pipeline consortiums planning export gas lines in the Northeast.

Projects approved are the 370-mile Iroquois Gas Transmission Systems' line; the 340-mile Champlain Pipeline Co project; and the 90-mile American Natural Resources Pipeline Co line. All three projects will handle Canadian gas exports from the western provinces.

The Iroquois project, estimated at around $440 million, will stretch from the Canadian border at upstate New York, south through that state and through portions of Connecticut to Long Island, NY.

The Champlain project will cross the Canadian border at Vermont, carrying gas south through Vermont, New Hampshire and Massachusetts. ANR's line involves a 90-mile spur through portions of Indiana and Ohio in the Midwest.

All three proposals still face FERC

Model	ISO Base Load Shaft NG Fuel	Heat Rate	Efficiency	Ti Inlet	Air Flow	Press Ratio	Exhaust
M1A-11	1250 kW	14,600 kJ/kWh 13,840 Btu	24.7%	900°C	7.4 kg/s	9.0	470°C
M1A-13	1570 kW	13,900 kJ/kWh 13,180 Btu	26.0%	1030°C	7.3 kg/s	9.0	555°C
*MiT-13	3052 kW	14,300 kJ/kWh 13,550 Btu	25.2%	1030°C	14.6 kg/s	9.0	555°C
**M1A-13CC	2750 kW	10,300 kJ/kWh	35.0%	1010°C	7.1 kg/s	9.2	574°C

*twin turbine model with combining gearbox
**steam injected design, rating with max steam injection

International Power Technology

The Kawasaki M1A-13CC steam-injected gas turbine relies upon the Cheng Cycle technology developed by International Power Technology, Inc. of Redwood City, California.

For more information on the Cheng Cycle, please contact:

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